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State of the Art Review

Shanks, Kirk

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by
Dr K. Shanks,
Dublin Energy Lab.,
School of Architecture,
Faculty of the Built Environment,
Dublin Institute of Technology,
Ireland

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1.0 Introduction

Energy use behaviour is increasingly being recognised as one of the fundamental drivers of energy efficiency in buildings. Behaviour and driving behavioural change are now included in the aims of European(Anon.A, 2007) and national energy policy(Anon.B, 2007) and identified as specific factors in strategic national publications informing development, such as SEI's *'Energy in the Residential Sector'*(O'Leary, F., et al, 2008). It is the focus of national campaigns and initiatives in most countries and numerous local projects. It is being addressed by governments, NGO's, community groups and has been influential in the growth of new energy monitoring technologies and specialist business services. For example, in Ireland, targetting energy use awareness and behavioural change are core objectives of the following programmes:

- Power of One Street (at home, at work)
- Change.ie campaign
- Green Schools, Green Home programme An Taisce
- Race against waste
- Dundalk 2020

As energy consumption is a distinct factor in an organisation's carbon footprint, corporate social responsibility (CSR) policies and statements are increasingly including objectives on energy efficiency to address environmental performance. These are now common in most corporate governance missions, reflecting the the value of energy in business operations and the public interest in responsibility towards the environment.

With energy use behaviour being recognised as a distinct component of a sector's carbon emissions and energy consumption it also has direct implications on national objectives of maximising economic performance; minimising environmental impacts and increasing energy security. Due to this, behavioural factors are beginning to be addressed in standards and regulation. For example, the Irish standard IS393 sets out a framework for reporting energy management which provides a basis for identifying operational and behavioural components of organisations energy consumption. Similarly, the legal requirement for all public buildings to complete annual display energy certificates (DECs) provides a first level guage of the impact of energy use behaviour in an organisations building stock. As a DEC provides a certified rating of the difference between predicted and actual operational energy consumption, they give an indication of how energy is being consumed in comparison to standardised patterns of use.

Addressing behavioural dimensions of energy performance is an emerging priority in all sectors. This increasing level of interest has a number of drivers from policy and regulation, at national;

European and corporate levels, to management of energy items in operational costs base to greater public, and thereby individual, awareness of environmental impacts.

This State of the Art Review provides an overview of the main characteristics of operational energy costs and energy use behaviour in typical business organisations buildings including a review of the different types of technologies available to influence behaviour towards minimising the amount of energy consumed to meet the needs of building users.

2.0 Building operational energy consumption

Other than for industrial processes, energy is consumed in buildings to maintain comfortable, healthy and secure conditions and power equipment for building users and work activities. It is consumed for different end-uses, e.g. heat; light etc., to maintain indoor temperature levels, light levels, fresh air, hot water and power for appliances and equipment, e.g. photocopiers; computers, refrigerators etc. The range of end-uses in any building typically includes some or all of the following:

- heating
- hot water
- cooling
- fans and pumps
- lighting
- other small power (ICT equipment, appliances, controls, security, etc.)

The amount of energy needed to meet the demands of these end-uses varies from building to building depending on the requirements of different building functions, e.g. an office; retail unit; leisure centre; etc., as well as how a building is designed and the pattern of demand for end-uses. For example, the typical annual energy demands for a 1,000m^2 office differ if it is designed and serviced as an open plan, air-conditioned or cellular, naturally ventilated building. Similarly, demands and their profiles also differ depending on a building's functions, e.g. a small retail unit, an office or a leisure centre, see Figure 1 below.

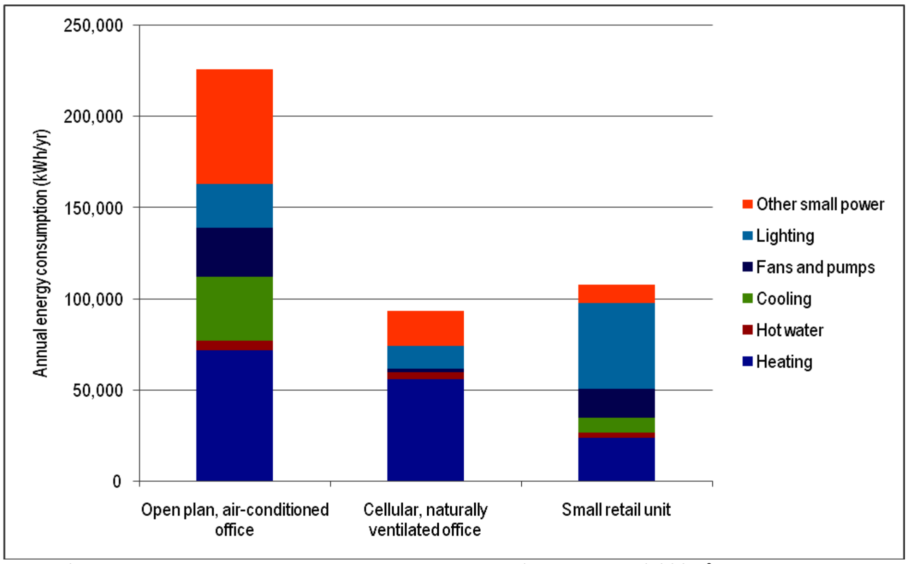

Figure 1: Typical annual building energy end-use demands for a notional 1,000m^2 building

As an example, a building, or part of a building, providing a typical office function has some particular types of characteristics such as, relatively high room temperature levels of 21°C; a moderate level of fresh air or ventilation demand related to the volume of air in office spaces; a limited need for hot water as this is primarily only needed for washing hands etc.; a high level of lighting and high level of power consumption for workstations; printers and photocopiers etc. These differ for a building which functions as a small retail unit, where there are slightly lower temperature level demands; lower demands for ventilation due to lower occupancy density; less overall demand for heating due to larger heat gains from lighting whilst also greater use of task or spot lighting and smaller quantities of other small power items and less need for hot water.

The generic differences between an air-conditioned and naturally ventilated office is that in an air-conditioned office the temperature level is controlled within a relatively narrow range, i.e. it is typically allowed to fluctuate between +/- 1 to 2°C of the optimum temperature, typically, 21°C, and the amount of fresh air ventilation is maintained at a fixed rate, requiring the use of fans to drive air through the building and office spaces. Controlling the temperature within limits like this can also require the use of mechanical cooling to bring office temperatures down when they overshoot the optimum. This can be due to a range of generic factors such as, increasing outdoor temperatures, heat gains directly from the sun or heat gains from people and power consuming appliances and equipment. There are some other typical differences in characteristics between air-conditioned and naturally ventilated offices that influence energy end-use demands including:

- an air-conditioned office will commonly have a deeper plan, i.e. work spaces further away from the building perimter meaning less availability of daylighting, than a cellular naturally ventilated office, resulting in greater energy demand for lighting
- an air-conditioned office will have more extensive control systems than a naturally ventilated office, resulting in greater energy demand for control systems
- cellular naturally ventilated offices typically have a lower density of building users, thereby having lower levels of heat gains from people and equipment, resulting in greater energy demand for heating

These examples illustrate how differences in function, building design and energy system characteristics affect the energy demands of buildings. However in practice, these are mainly estimated on the basis of benchmark figures based on theoretical calculations of energy flows which do not include variations in how different users interact with a building.

It is a rare coincidence that a building will consume the same amount of energy in reality than it is predicted to on the basis of theory. It is common that actual consumption is a multiple, two, three or more times, of predicted theoretical demands and consumption. Even with purposely designed low-energy buildings many examples have been found to have greater energy consumption in relaity than that expected from design (Bordas, W., et al, 2001). Whilst this can be due to a combination of reasons from construction quality to energy system maintenance to weather variations to introduction of new equipment, there are always the human factors of how a buidlings users interact with it and their energy consuming systems that directly influences the amount of energy consumption. (These types of human factors can be classed as behavioural and grouped as 'energy use behaviour.)

As energy use behaviour has a direct impact on energy end-use demand it is a key determinant of actual energy and fuel consumption and CO_2 emissions. Issues such as keeping room temperatures within acceptable levels or turning office equipment OFF at night can reduce energy end-use demands by as much as 10% each (Anon., 2006). Whilst some behavioural actions can have wide scale effect in a building, such as the many instances where control systems have been found to simply not be working; resulting in building wide systems having defaulted to ON (Bordass, W., et al, 2001), others have more local individual impacts that when adopted by many can have significant affects on overall consumption. The following examples illustrate some individual user behaviours that affect energy end-use demands:

Heating:	adjustment of thermostats in work spaces, inefficient opening of windows and not closing doors, overriding heating timer settings, leaving blinds open at night, variations in perceived comfort demands across an office population leading to wide variations in heating demands

Hot water: leaving taps running when not needed

Cooling: similar to heating issues and not utilising blinds to reduce solar heat gain, adjustment of thermostats in work spaces and leaving on or at most inefficient level while not using the work space, inefficient use of windows and doors

Fans and pumps: these end-uses are affected directly by heating, hot water and cooling demands as well as leaving ventilation fans on and not using windows and doors efficiently

Lighting: leaving lights on when not needed, e.g. night, overriding automatic controls, not making use of task lighting or daylighting

Other small power: leaving ICT equipment on when not needed, not making use of sleep/hibernate software functions, inefficient use of appliances in kitchens

The proportional influence of end-uses differs from building to building where identifying which end-uses have the greatest potential for savings is a first step to changing the behavioural impact in a building. For example, the sample building type benchmarks below indicate where priorities would differ depending on function. Although these benchmarks are over 10 years old they provide an indication of the variations in the proportional impact of typical generic energy end-uses between some different building functions:

Building function	Space heating	Lighting	Hot water	Other	Catering / cooking	Ventilation
High street bank	67	19	4	10	***	***
Fast food outlet	3.5	1.5	24	1	70	***
Office (with AC)	48	16	6	1	***	29
Restaurant	25	15	15	***	40	5
Warehouse	80	8	2	10	***	***

Table 1: Typical annual energy end-use percentage composition for sample building functions, adapted from UK Energy Efficiency Office Guides (%)

In many cases, building operational energy costs are second only to labour costs in typical business operational costs, such as staff; materials; property rental; etc. Energy and fuel costs are a specific accounting line item in the annual operating costs of all businesses and organisations. These building energy costs are affected by prevailing market prices for fuel and electricity and the level of energy efficiency achieved. Where shopping around for lowest fuel costs and electricity tariffs maximises opportunities to respond to market price variations to minimise the rate paid for all the energy consumed, there are a number of different types of factors involved in addressing just how much energy an organisations buildings consume.

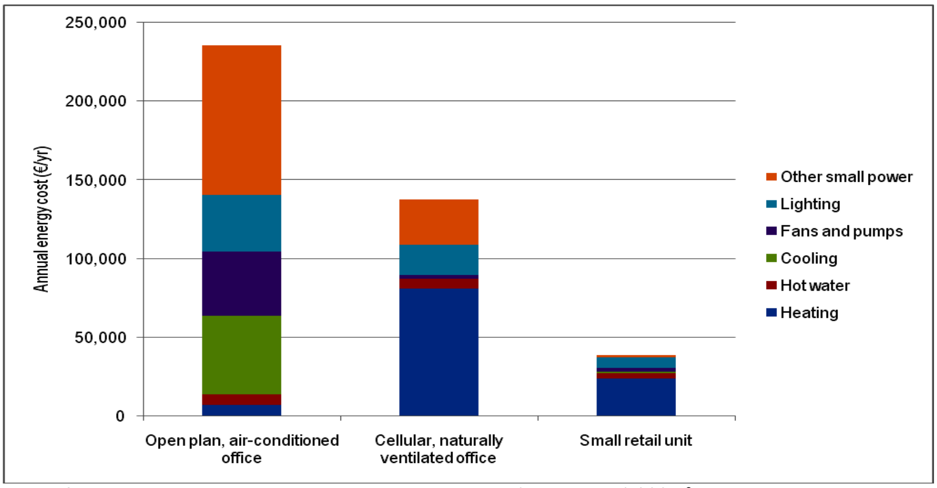

Figure 2: Typical annual building energy costs by end-use for notional 1,000m^2 building

As measuring actual energy consumption can directly help planning and implementing actions to reduce energy costs there are trends emerging in European member states to move towards regulatory requirements for 'operational ratings' of buildings to be included in non-domestic Energy Performance Certificates (EPC) as part of the implementation of the EC Energy Performance of Buildings Directive (Anon., 2002). This 'operational rating' is based on measurements of energy consumption and, in comparison to theoretical benchmark figures, has great value in telling organisations how efficient their buildings are being used. Such certificates are expected by investors to make tenants '...more aware of how buildings perform and will be prevalent during lease negotiations.'(Anon., 2009). EPC's in the form of Display Energy Certificates (DEC) have been a legal requirement in Ireland, for all public buildings, since January 2009.

Operational, or actual, energy consumption is the foremost measurement that gives an insight into how a building is being used and is therefore an ideal indicator of behaviour. By tracking actual energy consumption over time, e.g. hour to hour, day to day or month to month, it is possible to quantify the savings due to changes in energy use behaviour as well as actual savings from energy efficiency technology investments.

3.0 Energy use behaviour

Behavioural science research has found that building users' energy related actions are primarily determined by habits formed and these habits are a result of complex interactions between individual, group and situational factors of workday routines. In the workplace factors that influence energy using habits range from aspects of an organisations culture to awareness of energy use costs and benefits to capacities to take energy efficient actions.

There continues to be a growing body of work on understanding how factors interact to drive energy use behaviour and what factors can influence change in behaviour. One of the simplest frameworks developed to map the various factors is the ABC theory(Stern, 2000). It maps behaviour as a product of personal attitudes, technical and personal capabilities and contextual factors. In the context of energy-use behaviour in buildings, this means that, how and why building users take actions in their workplace is influenced by their attitudes to the environmental and financial costs, what actions are within their sphere to be able to take and the community within which they are working. Where these factors combine to create habits and routines the common element between attitudes and contextual factors is awareness. Awareness of costs and benefits of routines and inherrent actions that have an impact on the efficiency of energy use can be a key influencer of behaviour.

The main factors influencing behaviour that have relevance in organisations include(after Stern, 2000):

- Attitudinal
  - General environmentalist predisposition

    - Nonenvironmental attitudes (i.e. attitudes based on attributes of products and systems being used or available for use)
    - Perceived costs and benefits of actions
- Capabilities within the personal worksphere
    - Knowledge and skills
    - Organisational status
    - Financial resources
- Contextual
    - Material costs and rewards
    - Rules and regulations (e.g. standard operating procedures)
    - Available technology
    - Peer group norms and expectations
    - Supportive policies
    - Advertising

Considering these factors, there is an extensive range of possibilities for influencing pro-energy efficient attitudes and establishing contexts to give greater potential for using energy efficiently within organisations'. Generically, these vary across the different levels within an organisation, i.e. corporate level, departmental or team level and at the level of individuals' work spaces.

Corporate

At the corporate or organisational level research has found that standard operating procedures are a key factor in determining and influencing 'environmentally significant behaviour' (Stern, 2000), similar to energy use behaviour. This is because standard operating procedures establish and support ongoing habits. Similarly, other corporate governance tools help define an organisations culture and frame the objectives of its operations. For example:

- Mission Statements can define aggregated energy and carbon efficiency aims of an organisations operation
- Procurement policies can include clauses that define the energy efficiency credentials of purchased equipment and consumables
- Reporting procedures, annual reports etc., can include specific accounting of energy and associated environmental costs related to business group performance and activity

Departmental or Team

The departmental and team level provides interpretation of corporate level aims to the day to day running of operations. These levels are where the processes and regular procedures are set in place. Here energy targets can be quantified and set, reporting and auditing systems can be defined and operationalised and initiatives targetted at effectively increasing awareness can be managed.

Approaches and initiatives set in place at this level have a direct impact on both raising awareness to influence personal attitudes and create the contexts for enhancing opportunity for individuals to take action.

Individual

Habits, based on attitudes and contextual factors, directly result in energy-use patterns at the level of individual workspaces. It is here that the effectiveness of approaches becomes evident and measurable. Whilst it has been found that well designed technical environment systems and products have great potential in reducing energy consumption and increase efficiency (Midden et al., 2007), it has also been found that feedback alone provides direct benefits for learning how to control energy use efficiently (Darby, 2006).

As noted above, contextual factors influence energy use behaviour; it is at this individual level that contextual factors such as social norms, i.e. those of individuals' neighbours in a work environment, and the individuals' capacity to control energy consuming systems and equipment become of greater influence on behaviour than personal attitudes(Guagnano, et al, 1995).

Within these types of approaches, technology can play a significant role in raising awareness and motivating behavioural change. The design, functionality and accessibility of technologies are key determinants in their success in supporting energy efficient behaviour(Midden, et al, 2007).

Contextual factors can be more technical and result in placing limits on the potential for energy efficient behaviour. A typical simple example of this comes from a a post-occupancy study of an office building in the UK where although there was no business related need for PCs to be on overnight, they could not be turned off due to being interlocked with the buildings security system(Usable Buildings Trust, 2002). In this example feedback would have highlighted the inefficient use of energy through the night and driven the adoption of operating procedures to remove this energy load. Then implementation would have found the technical barrier to realising the target change in behaviour. The value of addressing this type of example can be seen from a study in the USA. In its study of 1453 desktop PC's in 12 different large buildings, the study found that 60% were left on after work hours with only 6% in automatic low power mode(Webber, et al, 2006). With a typical power consumption of a desktop PC in the on mode of 55W and in the off mode of 5W(Kawamoto, et al, 2004) the potential of savings is significant.

This highlights a consistent theme emerging from environmental and energy use behavioural research where feedback techniques, such as different types of energy information systems, combined with other instruments are proven to drive changes in behaviour that result in savings. Domestic studies reinforce this where findings show that feedback does have a 'marginal statistically significance on total percentage change in consumption', and that feedback is 'more effective when targetted (behavioural potential), particularised and visible'(Brandon & Lewis, 1999).

Whilst some mass-media campaigns, such as the Power of One in Ireland,have been found to have no affect on changing behaviour to the extent that resultant savings become evident in regional consumption figures(Malaguzzi-Valeri, L., et al, 2009) to the extent that there is a noticeable impact on aggregated national consumption figures, combinations of approaches, including elements of media and advertising use do have an impact on raising awareness, which is one element of changing behaviour. For example, a sub-activity, Power of One Street, within the national campaign Power of One provided particularised feedback to two business organisations and a school over a six month period resulting in an average reduction in fully measured heating consumption of 9%(DCENR, 2008). Effectively the mass media campaign raised awareness of generic behavioural aspects of energy use which was then supported by site specific feedback based on measurement. With increased awareness, of energy impacts, individuals will typically be more motivated to explore changes to their energy-use behaviour.

Changing energy use behaviour in an organisation is a process. It relies on a range of different approaches and techniques which can be applied at all levels within a workforce and is most effective when underpinned by relevant and particularised feedback.

4.0 Energy management and information techniques providing feedback

There are a wide range of techniques and technologies for management of energy in buildings from the scale of individual controls on heat emitters, e.g. thermostatic radiator valves (TRV's), to centralised building energy management systems (BEMS) comprising multiple networked sensors and actuators controlled via intelligent software. These types of control systems differ from energy information systems (EIS). The difference being, an energy management or control system gives information on energy and related operational parameters as well as providing means of taking automatic control action, e.g. adjusting a temperature setpoint on an air-conditioning system or switching lighting circuits ON and OFF. Whereas, an energy information system simply provides information or feedback on energy consumption therefore not providing any automatic control functions. Whilst some advanced EIS give intelligent guidance of where energy may be being used inefficiently, they do not provide any type of control action. The 'control action' is left to the user to decide and implement. EIS are limited to this information service type of function as they have a specific aim of influencing user energy behaviour as opposed to controlling energy systems under a pre-defined set of rules.

BEMS are highly engineered systems and many have advanced artificial intelligence based software which learns how a building and its energy systems function over time and adjusts control of these to best suit prevailing conditions, e.g. occupancy mode and external weather conditions. One advanced technique that makes use of all the technical information available in a BEMS is monitoring and targetting (M&T). With this technique the current status of energy parameters are compared to historical patterns and targets are set for influential parameters to optimise energy efficiency. The BEMS can then notify the operator when these targets are being exceeded and corrective action or adjustment of systems can be taken.

M&T can be used to investigate the financial performance of new energy-conservation investments, e.g. new glazing systems or new high efficiency condensing boilers etc., using approaches such as that reported by Swords(Swords, et al, 2008). However, whilst BEMS can be highly advanced technical systems they are still subject to human factors, from the behaviour of the systems operators to that of occupants use of spaces in general. In most buildings the communicative link between BEMS and building occupants, i.e. its users', is normally the BEMS operator or the buildings Facility Manager. In many situations, particularly in small and medium sized buildings, there is no particular person with a dedicated role of operating the BEMS or managing energy. Similarly, BEMS do not commonly make direct associations between a performance irregularity and the action of a building occupant and thereby cannot automatically provide a suitable control adjustment that will necessarily result in increased efficiency. Conversely, some advanced EIS, such as that by ResourceKraft, provide M&T and associated alerting, see Figure 3 below, but direct this information to those with financial responsibility for energy consumption.

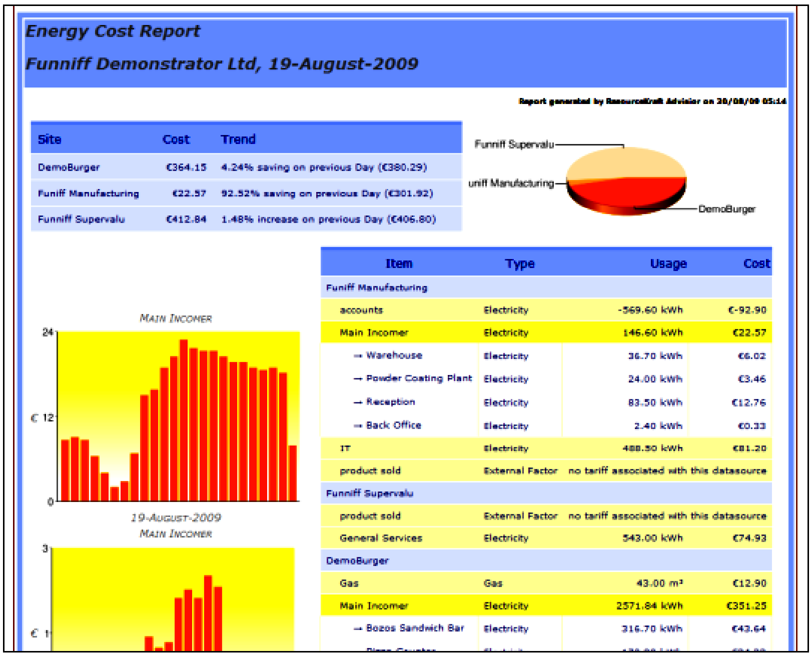

Figure 3: Example M&T financial reporting (Courtesy of ResourceKraft Ltd., Ireland)

In comparison to the centralised nature of BEMS where information is typically only used by building managers, EIS target users of energy directly. Advanced automated M&T systems, such as that adopted by Leicester City Council in the UK(Fereira, et al, 2007), can alert building managers to irregular or unexpected patterns in consumption which enables better energy management to reduce consumption. However, where such alerts relate to usage behaviour as opposed to equipment technical problems, this type of intelligent system treats the symptom as opposed to the cause.

Systems providing information more directly to the end user, such as smart metering, have been found to be effective in reducing electrical energy consumption. However whilst this has significant potential in housing, where a single metering point accounts for a comparatively small number of electrical end-uses, it is less relevant for large organisation with multiple spaces, departments or buildings. Smart metering does provide a platform on which different types of feedback, e.g. content; comparison; etc., can be provided but this is less likely to be sub-metered down to the end-uses needed to provide useful feedback to the wide range of users or user groups that would be in medium or large organisations.

Another type of systems providing feedback are EIS, where the primary function is to provide useful feedback directly to users and those responsible for consumption. Most types of feedback to date are one-way, i.e. to the user, but some research(Midden, et al, 2007) indicates greater potential in 2-way, or interactive feedback.

There are many different feedback techniques, each can be categorised as being either direct or indirect. Direct feedback is presented immediately, e.g. readings on electricity meters or displays, whereas indirect feedback has been processed in some way before being presented to the user, e.g. utility bills. The main characteristics of feedback techniques, from a review of 26 international studies(Fischer, 2007), that affect success in influencing changes in behaviour include:

- frequency
- duration
- content
- breakdown
- comparison
- additional information
- other instruments(Fischer, 2007)
- medium of presentation

Studies over the past 20 years consistently show that increased frequency of feedback is key to its effectiveness in driving user learning and motivating behavioural change. However, there are limitations to how frequent particular types of feedback can be provided. At one end of the frequency scale, feedback of instantaneous consumption can be constant but this type of information can be difficult to understand and interpret for most non-expert users. At the other end of the scale, whilst breakdown by end-use in monthly or quarterly billing can be useful, on its own it will be too little detail to enable the user to link any part of their behaviour with a level of consumption.

The most common contents of feedback are costs, e.g. €, and energy, e.g. W or kWh's, with potential for also including environmental metrics such as tonnesCO_2. Whilst costs and energy are understandable to most users the added value of environmental metrics is not yet well established. In commercial organisations relating levels of consumption to other business metrics such as key performance indicators (KPI's), e.g. kWh per unit of business output, has potential to engage users for who the feedback is aimed.

Feedback can be aggregated or broken down into smaller parts that represent individual or smaller grouped energy end-uses. Aggregated values cannot reflect the smaller individual changes in behaviour whilst smaller end-uses require sub-metering and more extensive monitoring or measurement systems. Research indicates that feedback broken down to end-uses is most effective in supporting behavioural change(after Fischer, 2007).

Most comparison approaches to date have been either comparison to historical patterns or comparison to similar generic benchmarks. Where the former has potential to indicate consumption changes due to changes in behaviour, amongst other factors, the latter can provide a compelling basis to investigate users' individual energy-use. However, neither have been found to consistently drive reductions. As the aim of most comparison techniques is to compare users consumption to some norm, finding one that is most relevant to an individual user or group of users does have great potential in being a key element of driving behavioural change.

Feedback that is accompanied by other information, e.g. tips on how to reduce energy consumption, etc., does not always increase the effectiveness of the feedback. In the current public sphere where there is alot of information on reducing energy consumption and carbon footprints, additional information can potentially confuse users resulting in lower engagement with the feedback. Research is inconclusive on the added value of additional information(Fischer, 2007) however behavioural theory does point towards benefits when additional information is particular to individual users, as in a tailored approach to feedback.

Following behavioural theory, the use of other instruments, e.g. targets; financial rewards; etc., in combination with feedback should increase the effectiveness of feedback. This however, has only been shown in laboratory based studies(McCalley, Midden, 2002) and not in field studies.

The medium of presentation used to give feedback to users, directly influences their level of engagement and determines the scope in frequency, duration, content, etc. Feedback through computers creates a platform on which to provide a wide range of content and functionality that gives the user greater choice and control over the information they view. Whereas, billing based feedback has a much more limited capacity. Whilst there have been few studies of the effectiveness of different visualisation techniques in presenting energy feedback(Fischer, 2007) some generic visualisation techniques have promising potential to minimise the amount of cognitive processing needed by users and thus convey information faster and more intuitively. Combinations of text, graphs and charts have been found to be more useful than using a single type of presentation whilst sensory based techniques such as the use of colours and sounds are the foundation of emerging persuasive technologies(Midden, et al, 2007).

Although research to date gives indications of the benefit of different feedback characteristics there is very little research in the area. Where most of the research to date on some characteristics is inconclusive it is viable to assume that the most effective combinations of feedback characteristics will depend heavily on the particular context and situation. Feedback techniques can have a generic framework but their successful application should be tailored to each situation. In large organisations this will depend on the situation regarding each of the behavioural factors outlined in section 3 above. In the commercial sectors, characterised as organisations with multiple buildings of similar operation, feedback can be more easily rolled out across the organisations building stock.

5.0 Conclusion

There are a number of drivers pushing the increasing prioristisation of better managing operational energy consumption. These range from adherrence to regulations as well as better business management through control of cost bases.

Energy-use behaviour is a distinct component of operational energy consumption. Operational energy consumption and the potential for savings from changes in user or workforce behaviour varies generically by building function and technical design. The technical and behavioural factors determining this consumption can be identified and utilised to reduce consumption and thereby reduce operational costs. Advanced EIS with M&T functionality, as shown by ResourceKraft, are key platforms to identify and monitor these technical and behavioural factors.

Programmes, or projects, to influence behaviour are best applied, in different ways, across all levels of an organisation. The success of these types of programmes relies heavily on different tailored types of feedback which can be enhanced when accompanied by awareness information and other instruments associated with specific types of behaviour.

Whilst the field of energy-use behaviour has been growing since the 1970's, the field of energy-use feedback is just emerging. Key future developments will focus on enhancing the effectiveness of feedback techniques to drive behavioural change and maintain energy efficient behaviour such as the examples of feedback approaches shown in Figure 4 below.

Figure 4: Examples of emerging energy use feedback techniques (Courtesy of ResourceKraft Ltd., Ireland)

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